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RESURRECTION OF BAIT AVERSION AND MANAGEMENT STRATEGIES FOR THE GERMAN COCKROACH (BLATTODEA: BLATTELLIDAE)

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Abstract Bait aversion has recently resurfaced, approximately six to ten years after the first known case of bait aversion (glucose aversion) was corrected. Anecdotal reports from Pest Management Professionals have indicated poor acceptance and control failures on commercial cockroach gel baits since late 1999. We initiated a program to collect and evaluate cockroaches from accounts reporting control failures with Maxforce FC and other commercial gel baits. Laboratory studies confirmed that gel baits were significantly less effective in control of the field-collected strains than the susceptible laboratory strains and that bait aversion was evident. Since Maxforce FC is not formulated with glucose, the scattered declines in efficacy across the United States were due to other factors. Rotations between major commercially available gel baits did not reverse control failures. After several years of lab and field trials of 50 experimental gel formulations, Bayer Environmental Science developed Maxforce FC, which has been effective against all bait aversive German cockroach strains. We provide recommendations for effective cockroach management program in the presence of potential bait aversion.
Key Words Bait avoidance, *Blattella germanica*, control failure, management strategy

INTRODUCTION

Non-repellent toxic baits are widely used insecticides for cockroach pest management in the United States (Reierson, 1995; Robinson and Zungoli, 1995). Among bait types, gel baits are the preferred formulation among pest management professionals (PMPs) (Mileo et al., 1986; Appel, 1992; Reierson, 1995; Appel and Tanley, 2000; Morrison et al., 2003). However, there have been reports of insecticide resistance (Schal, 1992) and bait aversion (Silverman and Bieman, 1993; Silverman and Ross, 1994; Wang et al., 2004) in the German cockroach, *Blattella germanica* (L). Since 1999, anecdotal evidence of bait aversion occurred, about six to seven years after the glucose aversion problem was corrected (Bieman et al., 1993). Harbison et al. (2003) estimated that 5-10% of the professional service accounts in the U.S. had experienced reduced performance with commercial gel baits.

Bayer Environmental Science (BES) began a program to investigate the spread of presumed bait aversion and the underlying mechanisms, and develop new formulation and product solutions. We report here research findings of bait aversion in *B. germanica.*

MATERIALS AND METHODS

Cockroach Strains

Nine suspected bait aversive *Blattella germanica* field strains and a lab strain, Orlando Normal (LABS) were evaluated (Table 1). The Orlando Normal strain has been maintained in the laboratory for over 50 years without insecticide exposure. Suspected aberrant feeding *B. germanica* cockroaches were live collected by either BES field researchers or pest management professionals (PMPs) from their respective service accounts where control failures were initially reported to Maxforce Roach Killing Gel Bait (MF gel), Maxforce FC Roach Killing Gel Bait (MF FC) or other commercial cockroach gel baits. The T-164 strain was known for its aversion to glucose (Silverman and Bieman, 1993). Strains were reared for a generation or until a sufficient number of individuals were available for bioassays. All insects were provided with water and rodent chow ad libitum and maintained at 25º ± 2ºC, 60 ± 20% RH and a 12:12 L:D photoperiod. Strains with confirmed aversion to the test gel baits were placed under a periodic selection pressure with either MF, FC or other commercial gel baits along with normal rearing diet to maintain the aversive traits.

Table 1. List and brief history of the German cockroach strains used in this study.

Strain	Location of Collection	Year
CNC	Charlotte, NC	2003
CCNY	White Plain, NY	2003
DBFL	Daytona Beach, FL	2003
FR	Victoria, TX	2002
KA	Dallas, TX	2002
LABS	(Orlando Normal)*	>50 years in Lab
MIAM	Miami, FL	1999
PCNC	Pender County, NC	2000
RHB	Dallas, TX	2002
T-164	Gainesville, FL***	1989

* = Orlando Normal lab strain (Silverman and Bieman 1993)

Efficacy of Baits

Gel Baits. Three major commercial cockroach gel bait products were used to assess the behavioral responses of the test strains in this study: Maxforce Professional Insect Control Roach Killer Bait Gel (2.15% hydramethylnon, Bayer Environmental Science, Montvale, NJ. [Maxforce gel]), Avert Cockroach Gel Bait (0.05% Abamectin B1, Whitmire Microgen Research laboratories, St. Louis, MO. [Avert gel]), and Siege Cockroach Gel (2.0% hydramethylnon, BASF, RTP, NC. [Siege gel]). The new Maxforce FC Select Professional Insect Control Roach Killer Bait Gel (0.01% fipronil, Bayer Environmental Science, Montvale, NJ. [Maxforce FC Select]) was also tested.

Solid Bait Station Versus Gel Bait. Maxforce gel and Avert gel baits were tested against two solid bait stations: Maxforce Professional Insect Control Roach Killer Small Bait Station (2.00% hydramethylnon, Bayer Environmental Science, Montvale, NJ. [Maxforce bait]), and Avert Cockroach Bait Station (0.05% Abamectin B1, Whitmire Microgen Research laboratories, St. Louis, MO. [Avert bait]).

The laboratory test arena consisted of a plastic container (32 x 22.5 x 13 cm) coated with a thin layer of petroleum jelly:mineral oil (2:3) mixture at the inner top 1/3 surface to prevent the insects from escaping, a water vial, harborage, and lab diet. Twenty adults (10 male and 10 female) and 20 nymphs (mixed gender third and fourth instars) were randomly selected and introduced into the test arena for 1-3 days prior to bait treatment. Dead individuals were replaced before bait treatment. After the acclimation period, baits were introduced and mortality was recorded after 1, 4, 7 and 10 days. Dead insects were not removed during the test period. Tests were replicated 4-6 times per treatment, depending on insect availability. Mortality in the controls was used to correct mortality in the treatments (Abbott, 1925). Mortality data were transformed by arcsine of the square root and analyzed by analysis of variance (ANOVA).

Sugar Consumption

D-glucose and several other sugars were selected for the sugar consumption assay. Each sugar was dissolved in 1% agar with 1M final concentration and paired with blank 1% agar for comparisons in consumption assays, where insects were deprived of food and water for 24 h prior to testing and exposed to the glucose-agar diets for 1 h. Test method and the feeding index as described in Silverman and Bieman (1993) for sugar x strain was used in this study:

$$\text{Feeding Index (FI)} = \frac{\text{sugar-agar diet consumed (mg)} - \text{agar-only diet consumed (mg)}}{\text{sugar-agar diet consumed (mg)} + \text{agar-only diet consumed (mg)}}$$

Feeding index for each 1M sugar was compared between cockroach strains with paired t- tests. Four replicates were performed for the paired sugar-agar assay. A positive feeding index suggests that the sugar stimulates feeding. A zero index value indicates that the sugar neither stimulates nor deters feeding, while a negative index reveals that feeding is deterred by the sugar.

RESULTS AND DISCUSSION

Efficacy Gel Baits

With the exceptions of the PCNC strain and T-164 strain against the Maxforce gel, all the other field-collected *B. germanica* showed significantly lower mortality (P<0.001) than the LABS susceptible strain after 10 days of bait exposure (Figure 1). The four strains (MIAM, CCNY, FR, and DBFL) showed a moderate level of bait aversion to all the three gel baits tested, which is representative of the majority of the strains we have collected and tested from other regions in the U.S. (Bao et al., unpublished data). The glucose aversive T-164 strain showed very distinctive responses to the three gel baits tested. The positive response to Maxforce gel was expected, since Maxforce gel does not contain glucose. The CNC, RHB, and KA strains showed poor responses to all the three gel baits tested, which represent the most severe cases of bait aversion studied to date. The PCNC strain showed similar susceptibility as the LABS strain to all the three gel baits, indicating no bait aversion is evident. The PCNC strain has a moderate level of resistance to several organophosphates and pyrethroids (Macom and Bao, unpublished data), but shows no aversion to the gel bait tested. This is very similar to the Dorie strain reported by Wang et al. (2004).

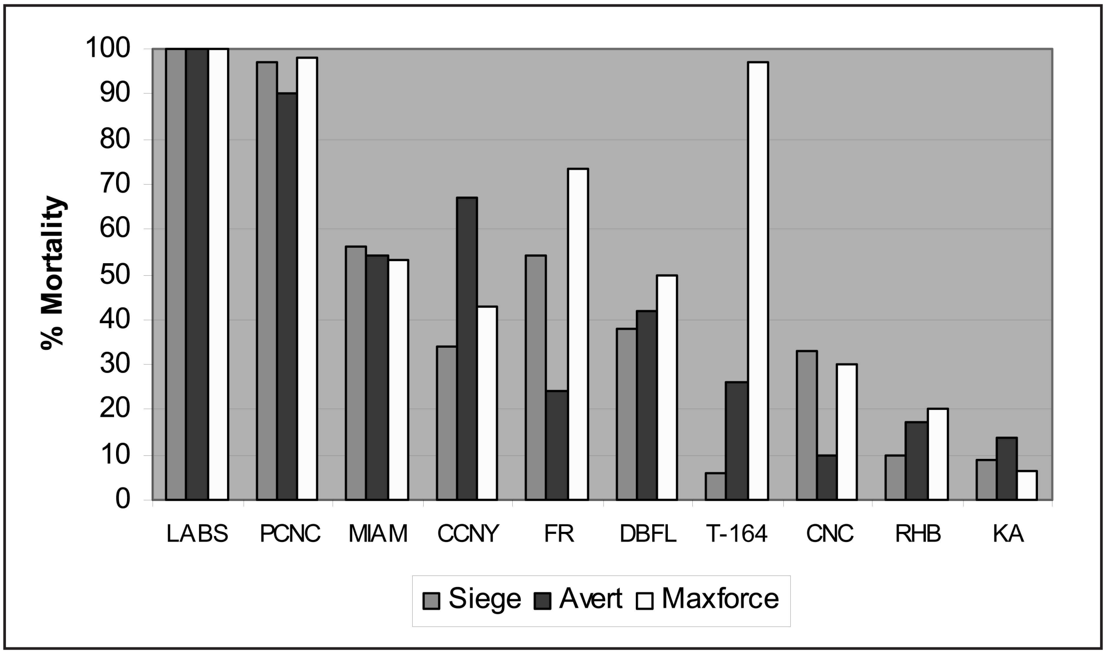

Figure 1. Efficacy of three major commercial gel baits against 10 laboratory and field-collected *B. germanica* strains. Mortality data shown were 10 days after bait treatment.

Lab test results confirmed the field observations, where low strain mortality corresponded directly to field control failures and poor bait acceptance. These initial reports were of single instances and locations were scattered in three distinct geographic locations: South Florida; the Dallas-Fort Worth Metroplex; and the New York City-North New Jersey Metroplex. Gel baits consistently performed poorly against strains collected from these regions compared to strains (e.g. PCNC) collected elsewhere.

Data presented in Figure 1 also suggested that simple rotations among the commercial gel baits may not provide the ultimate solution to overcome bait aversion, unless the underlying mechanism(s) is clearly identified and the aversive ingredient(s) is replaced, as demonstrated in the glucose aversion case (Bieman et al., 1993; Silverman and Bieman, 1993; Silverman and Ross, 1994). With the exception of the T-164 strain versus Maxforce gel, none of the bait aversive strains studied would reverse the poor efficacy by rotating from one gel bait to any of the others. This conclusion has been consistent with and supported by field reports from the PMPs, with rotation of gel bait products based on active ingredients and/or brands being ineffective.

Figure 2 shows the variable responses of the eight field-collected *B. germanica* strains against each of the four commercial cockroach gel baits, including the recently introduced Maxforce FC Select gel bait. Mortality at 10 DAT differed significantly among the eight field strains tested against Siege gel, Avert gel and Maxforce gel baits, respectively ($P<0.001$). No significant differences in mortality were found among the eight field strains treated with the Maxforce FC Select gel bait ($P>0.1$). Results suggested that bait aversion to Siege, Avert, and Maxforce gel baits was evident, and the current bait aversion in *B. germanica* was overcome by the new formulation, Maxforce FC Select gel bait.

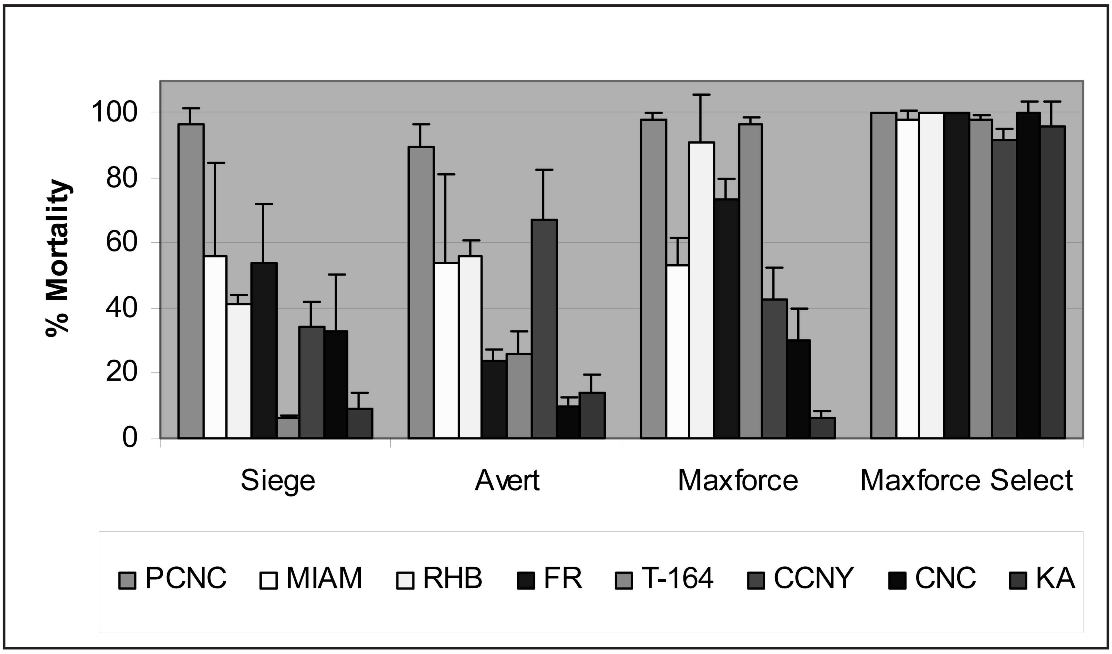

Figure 2. Comparative efficacy of eight field-collected *B. germanica* strains on four commercial gel baits. Mortality data shown were 10 days after bait treatment.

A lab study was initiated to compare Maxforce and Avert gels with their respective solid formulations in bait stations. There was a significant difference in mortality between the Maxforce gel and its bait station formulations against the bait-aversive RHB strain ten days after treatment ($P<0.001$, Figure 3). The Maxforce bait station provided 89% mortality, Maxforce gel bait produced 20% mortality at 10 DAT. We could not demonstrate a similar trend between Avert gel and Avert bait station against the *B. germanica* RHB strain. Wang et al. (2004) reported a moderate level of abamectin resistance (RR_{50}=6.8 and RR_{90}=10) in the Dorie strain than found in the Cincy strain (RR_{50}=2.5 and RR_{90}=3.9), but the reverse was true in terms of mortality from the gel bait treatment. Wang et al. (2004) reported that bait aversion was responsible for the poor efficacy against the Cincy strain, and may explain our results for the RHB strain. This generalization cannot explain the performance discrepancy between the Maxforce gel and bait station, even accounting for a lack of hydramethylnon physiological resistance. More studies are necessary to understand the underlying cause(s) before concluding prematurely that gelling agent in gel baits may be responsible. This is clearly not supported by the new gel bait, Maxforce FC Select, to which the RHB strain showed no sign of behavioral avoidance (Figure 2).

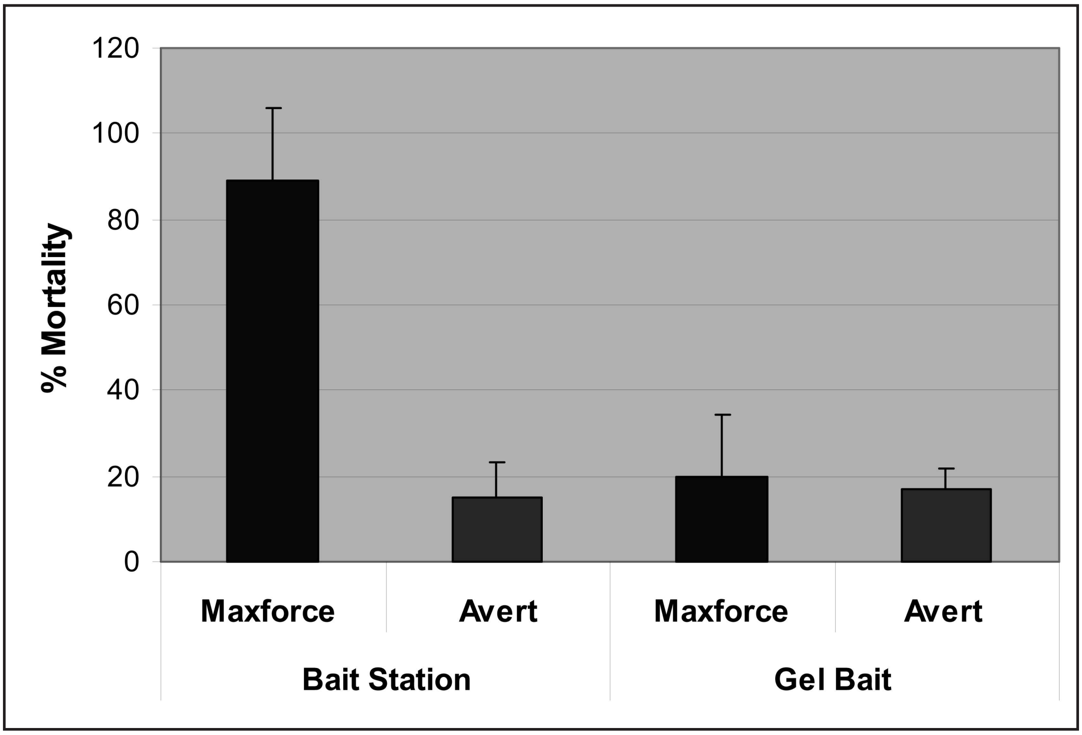

Figure 3. Comparative efficacy of gel baits versus bait stations against field collected *B. germanica* RHB strain. Mortality data shown were 10 days after bait treatment.

Sugar Consumption

The glucose feeding index (Figure 4) showed that the *B. germanica* KA strain had a positive but significantly less feeding preference on glucose than the LABS normal strain (P<0.001). Although the positive feeding index suggested that glucose stimulated feeding for the KA cockroaches, the notably lower feeding index indicated that such stimulation had been considerably diminished. Table 2 summarized the feeding index of six field collected *B. germanica* strains, and their responses to the 1M glucose were mixed. Two out of the three most aversive strains (CNC and KA, Figure 1) had reduced but positive feeding index, but the RHB strain clearly rejected glucose. The ALA strain also strongly rejected 1M glucose. These results indicated that glucose aversion continue to be responsible for some of the control failures reported recently. Moreover, since Maxforce gel does not contain glucose, feeding aversion to Maxforce gel baits suggested that other aversion mechanisms might have evolved. The *B. germanica* Cincy strain reported by Wang et al. (2004) rejected a number of sugars, including glucose, fructose, maltose, and sucrose, indicating that a bait aversive cockroach can possibly reject multiple sugar ingredients.

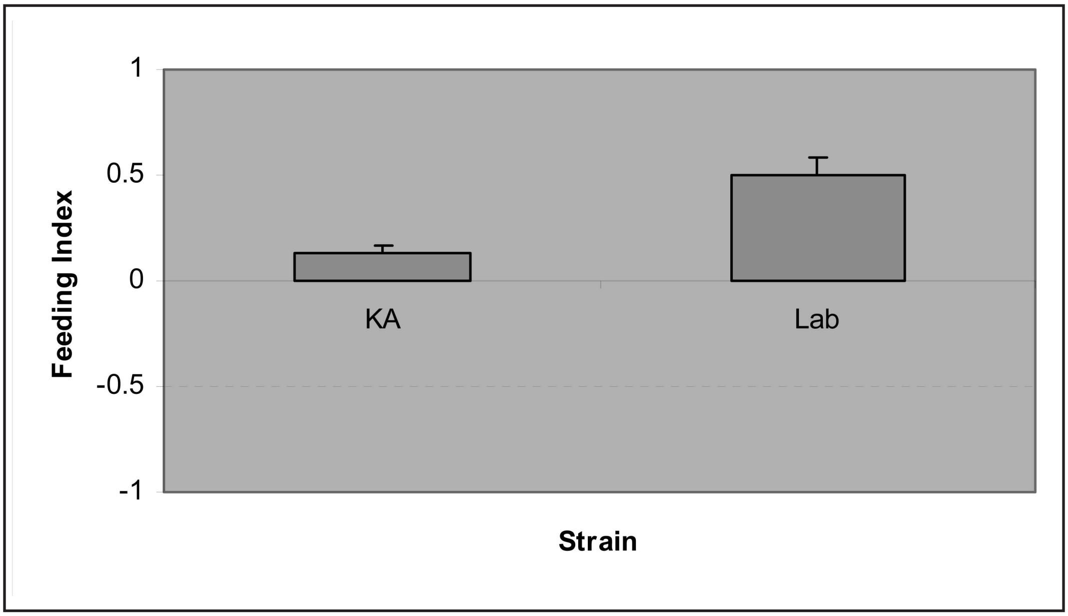

Figure 4. Paired 1M glucose-agar feeding assay of field collected *B. germanica* KA strain versus Orlando Normal lab strain.

Table 2. Paired 1M glucose in 1% agar feeding assay of six field collected *B. germanica* strains.

Strain	Feeding Index
ALA	-0.12
CNC	0.16
IHOP	0.02
KA	0.13
PCNC	0.10
RHB	-0.15

Bait Aversion Management

Bait aversion in the German cockroach poses a challenge to PMPs on how to effectively manage these cockroaches. This also challenges the bait manufacturers to reformulate new bait products and help PMPs to stay ahead of changes in cockroach feeding behaviors. With the established knowledge base we may preempt bait aversion, and thereby continue to rely on baits, including gel baits, to control German cockroaches. An IPM approach would appear be the best strategy and practice to manage German cockroaches and forestall insecticide resistance and bait aversion.

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